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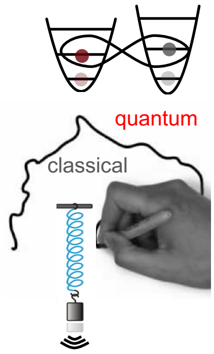

Using Light to probe Mechanical Oscillators in the Quantum Regime

EPFL

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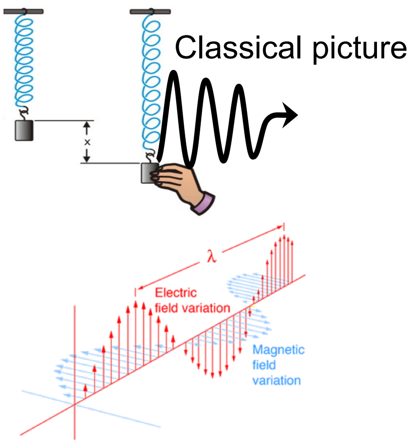
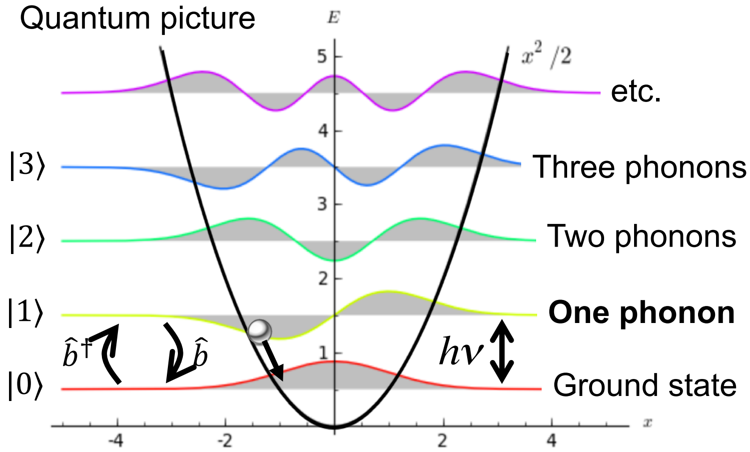
The Quantized Harmonic Oscillator

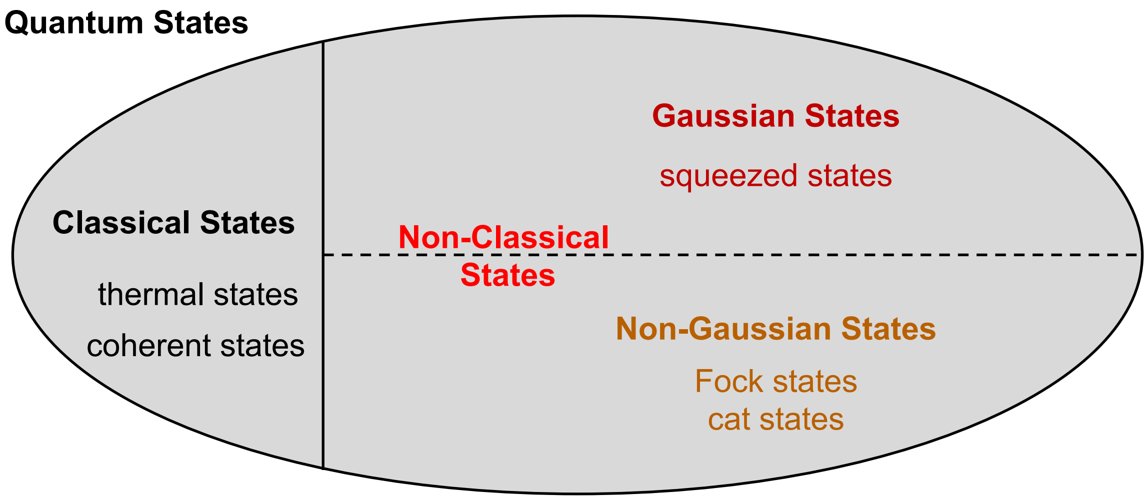




A photon is a quantum of electromagnetic energy

A phonon is a quantum of vibrational energy

Non-Classical States



NB: non-Gaussian classical states are possible https://arxiv.org/pdf/1411.5648.pdf

Coherent State vs. Number State Representation

Glauber-Sudarshan *P* representation:

$$\rho = \int P(\alpha)|\alpha\rangle\langle\alpha|\mathrm{d}^2\alpha$$

In the Fock state basis:

$$|\psi\rangle = \sum_n c_n |n\rangle$$

$$|n\rangle = \frac{(\hat{a}^\dagger)^n}{\sqrt{n!}}|0\rangle$$

$$\rho = \sum_{n,m} \alpha_{nm} |n\rangle\langle m|$$

Coherent state:

$$\rho = |\alpha_0\rangle\langle\alpha_0| \, ,$$

$$P(\alpha) = \delta^{(2)}(\alpha - \alpha_0)$$

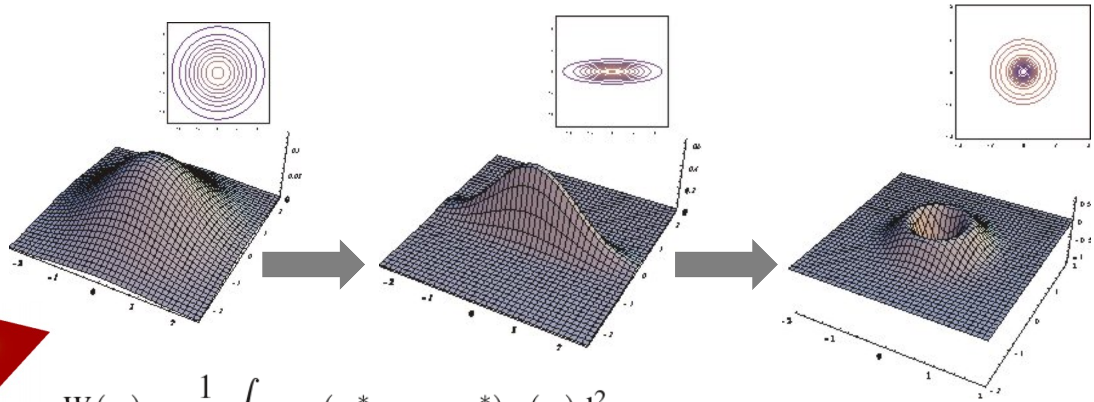
Thermal state:

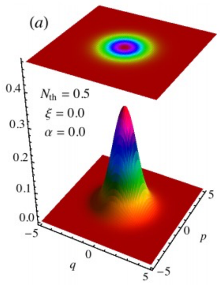
$$\rho = \sum P_n |n\rangle\langle n|$$

$$P(\alpha) = \frac{1}{\pi\bar{n}} \mathrm{e}^{-|\alpha|^2/\bar{n}}$$

Walls & Milburn, Quantum Optics, Ch. 4

Wigner Function





$$W(\alpha) = \frac{1}{\pi^2}\int \exp(\eta^*\alpha - \eta\alpha^*)\chi(\eta)\mathrm{d}^2\eta$$

$$\chi(\eta) = \mathrm{Tr}\{\rho e^{\eta a^\dagger - \eta^* a}\}$$

https://arxiv.org/pdf/1111.0786.pdf https://iqst.ca/quantech/wiggalery.php

The photodetection probability in term of the creation/annihilation operators

$\hat a^\dagger, \hat a$ $|e\rangle$ $\hbar\omega$ $\hat\sigma_+$ $\hat\sigma_-$ $|g\rangle$

$$\Rightarrow \quad \hat H_{int} \propto \underbrace{\hat a^\dagger \hat\sigma_-}_{\text{emission}} + \underbrace{\hat a \hat\sigma_+}_{\text{detection / absorption.}}$$

$\hat a \sim e^{-i\omega t}$

$\hat a^\dagger \sim e^{+i\omega t}$

(Single photon) Probability of detection : $\tilde P_{det} \propto |\langle f|\hat a|i\rangle|^2$

$$= \langle i|\hat a^\dagger|f\rangle\langle f|\hat a|i\rangle$$

$$P_{det} \propto \sum_f \langle i|\hat a^\dagger|f\rangle\langle f|\hat a|i\rangle = \langle i|\hat a^\dagger \hat a|i\rangle = \langle \hat n\rangle$$

Two-photon detection : $\langle i|\underbrace{\hat a^\dagger \hat a^\dagger \hat a \hat a}_{t=\tau\ t=0}|i\rangle = \langle :\hat n^2:\rangle$

↳ Normalized intensity correlation : $g^{(2)}(\tau) = \dfrac{\langle \hat a^\dagger(0)\hat a^\dagger(\tau)\hat a(\tau)\hat a(0)\rangle}{\underbrace{\langle \hat n(\tau)\rangle\langle \hat n(0)\rangle}_{\langle \hat n\rangle^2}} =$

$$g^{(2)}(0) = \frac{\langle :\hat n^2:\rangle}{\langle \hat n\rangle^2}$$

Mandel and Wolf - Optical Coherence and Quantum Optics (1995)

Classical bounds from Cauchy Schwarz inequality

$$f, g \rightarrow \left(\int f \cdot g\right)^2 \leq \int f^2 \int g^2 \qquad g^{(2)}(\tau) = \frac{\langle I(\tau) I(0)\rangle}{\langle I(\tau)\rangle\langle I(0)\rangle}$$

$$\hookrightarrow g^{(2)}(\tau) \leq g^{(2)}(0) \quad \text{since} \quad g^{(2)}(\tau \to \infty) = 1 \Rightarrow g^{(2)}(0) \geq 1$$

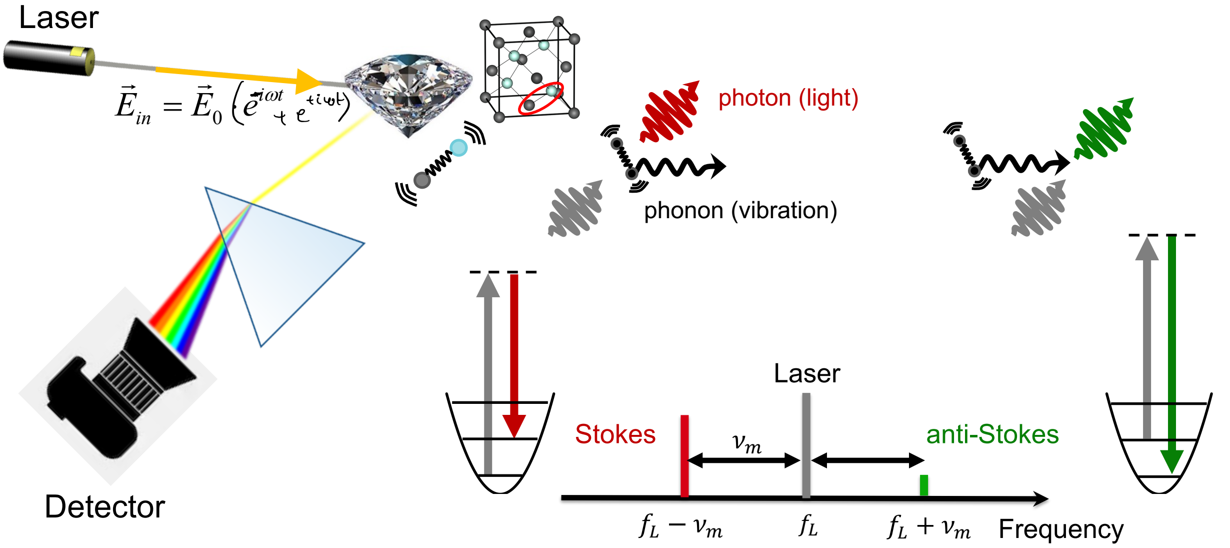
For 2 fields: $$g^{(2)}_{a,b} = \frac{\langle a^\dagger b^\dagger b a\rangle}{\langle a^\dagger a\rangle\langle b^\dagger b\rangle} \leq \sqrt{g^{(2)}_{a,a} \cdot g^{(2)}_{b,b}}$$

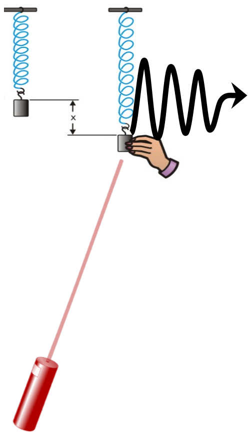
Projector for photon counting

$$I_{det} \propto \langle a^\dagger a\rangle \qquad P_n = |n\rangle\langle n| \rightarrow P_{click} = \sum_{n \geq 1} |n\rangle\langle n| = \mathbb{1} - |0\rangle\langle 0|$$

Input $|\Psi_{in}\rangle \rightarrow \left| P_{click} |\Psi_{in}\rangle \right|^2$ = probability of getting a "click".

Using photons to create and detect single phonons





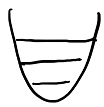
Goals and outline

Can we use coherent (laser) light and single photon detectors to reveal non-classical properties of a mechanical oscillator?

1. The thermal state of the harmonic oscillator
2. Interaction of light with a collective oscillation
3. Two-mode squeezing interaction
4. Projective measurement and conditional Fock state
5. State readout: subpoissonian statistics
6. From single phonons to entangled states

The Thermal State (chaotic light)

Density operator from statistical mechanics: $\hat{\rho}_{th} = \sum_n P_n |n\rangle\langle n|$ with $P_n = \frac{1}{Z} e^{-\frac{E_n}{k_B T}}$



$E_n = \hbar\omega n$

$$Z = \sum_n \left(e^{-\frac{\hbar\omega}{k_B T}}\right)^n = \frac{1}{1-e^{-\frac{\hbar\omega}{k_B T}}}$$

$$P_n = \frac{1}{Z} \tilde{p}^n$$

We can show that $\tilde{p} = \frac{\bar{n}}{1+\bar{n}} \Rightarrow P_n = \left(\frac{\bar{n}}{1+\bar{n}}\right)^n$

$$\hat{\rho}_{th} = \frac{1}{1+\bar{n}} \sum_n \left(\frac{\bar{n}}{1+\bar{n}}\right)^n$$

Mean occupancy (phonon number) $\bar{n} = \mathrm{Tr}(\hat{n}\hat{\rho}_{th}) = \frac{\tilde{p}}{1-\tilde{p}} = \frac{1}{\left(e^{\frac{\hbar\omega}{k_B T}}-1\right)}$

$\hbar\omega \ll k_B T \rightarrow \bar{n} = \frac{k_B T}{\hbar\omega}$

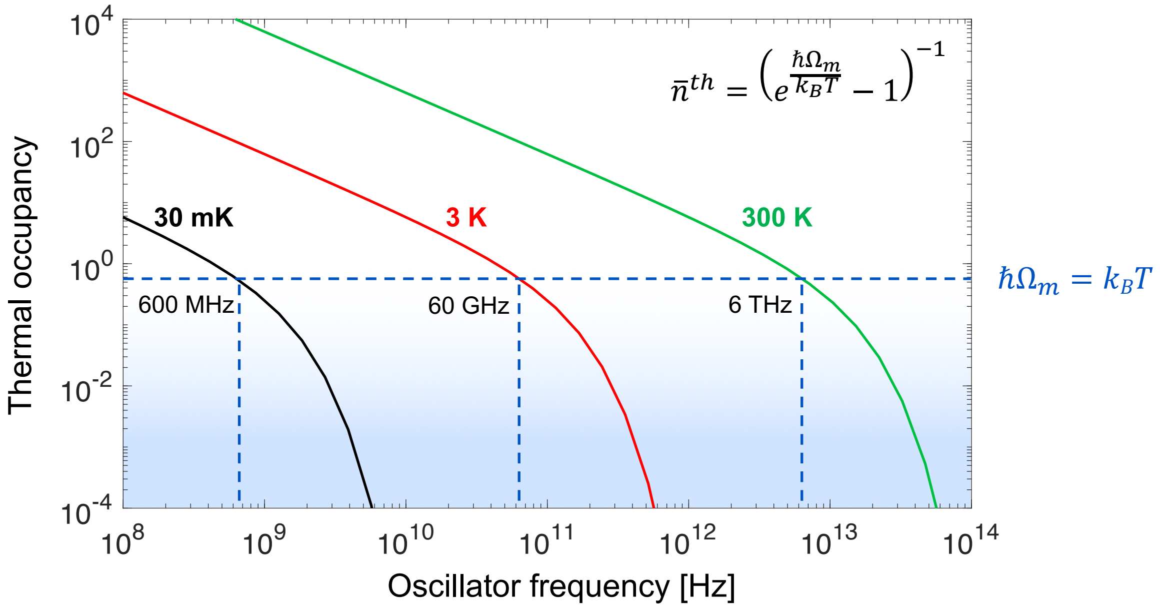
$\hbar\omega \gg k_B T \rightarrow \bar{n} = e^{-\frac{\hbar\omega}{k_B T}}$

$$g^{(2)} = \frac{\langle :\hat{n}^2: \rangle}{\langle \hat{n} \rangle^2} = 2 \quad \text{(single mode thermal state)}$$

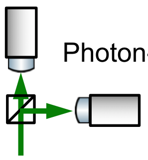
For a detector collecting the light from N modes: $\boxed{g^{(2)}_{th} = 1 + 1/N}$

Gerry & Knight, Ch. 2.5

The Bose-Einstein distribution

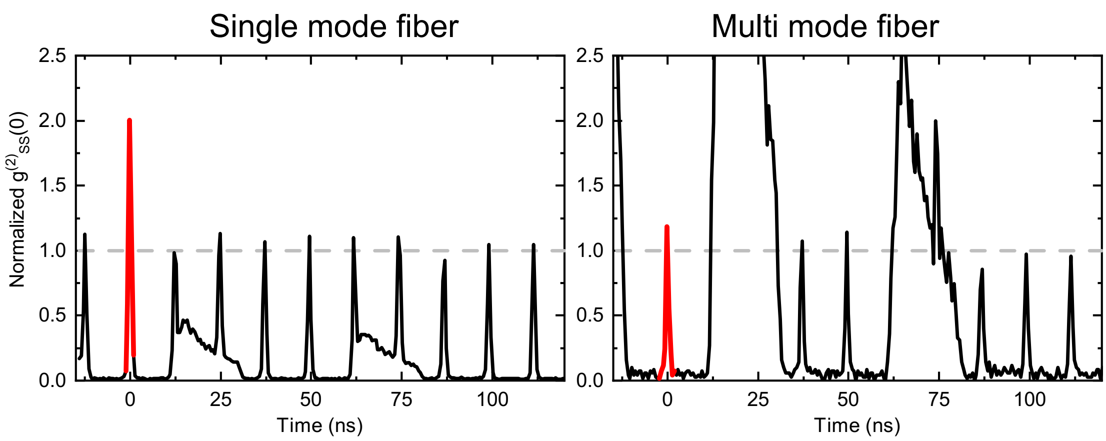


Single vs. Multi-mode thermal statistics



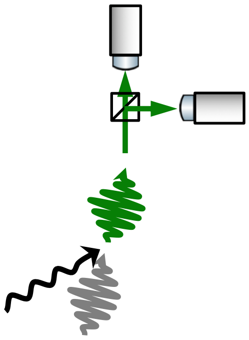
N modes:

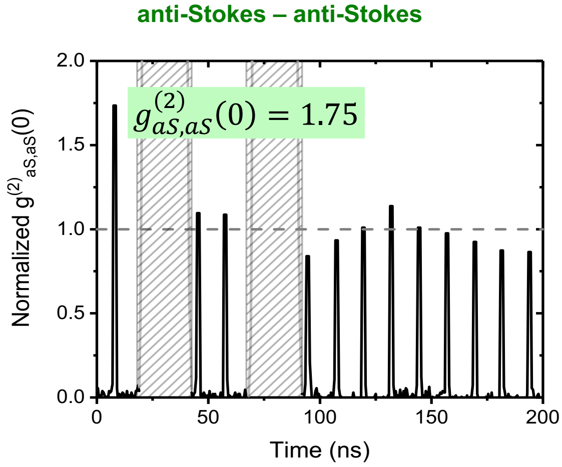
$$g_N^{(2)} = 1 + 1/N$$



Thermal Statistics of the Phonon Mode

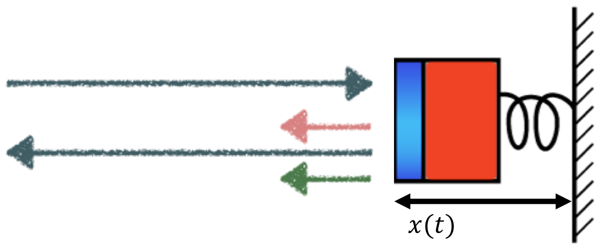
$\bar{n}_{th} = 10^{-3}$





N modes:
$g^{(2)}_N = 1 + 1/N$

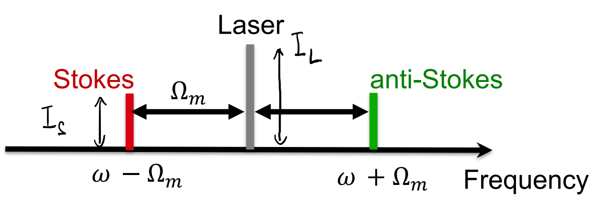
Interaction of light with a moving boundary



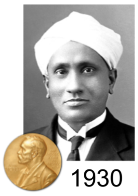
$x(t) = A_0 \sin(\Omega_m t)$

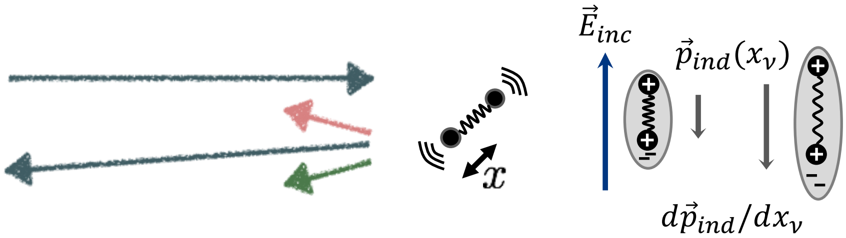
$E_{in}(t) = E_0 \sin(\omega t)$

$\frac{I_S}{I_L} \propto \left(\frac{A_0}{\lambda}\right)^2$

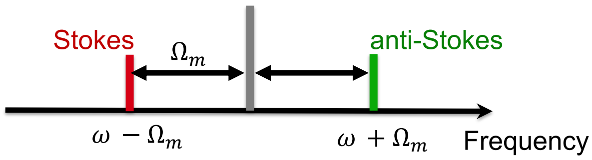


Interaction of light with an internal vibration





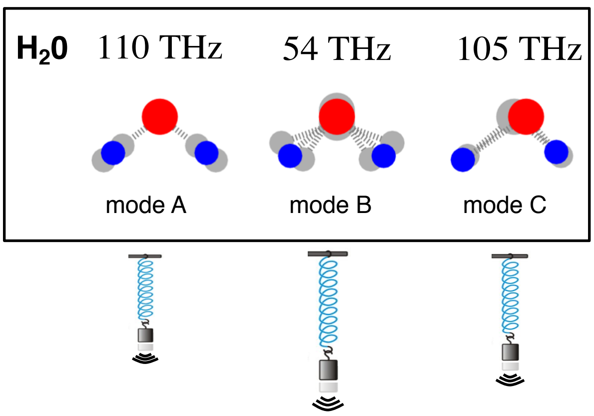
Raman spectroscopy



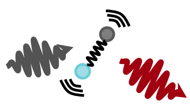
E.C. Le Ru and P. G. Etchegoin, *Principles of Surface-Enhanced Raman Spectroscopy and related plasmonic effects*, Elsevier , 2009

Derek A. Long, *The Raman Effect – A Unified Treatment of the Theory of Raman Scattering by Molecules,* 2002

Coupled Oscillators: Normal Modes



Raman cross-section
~10^{-29} cm^2 per C-C bond

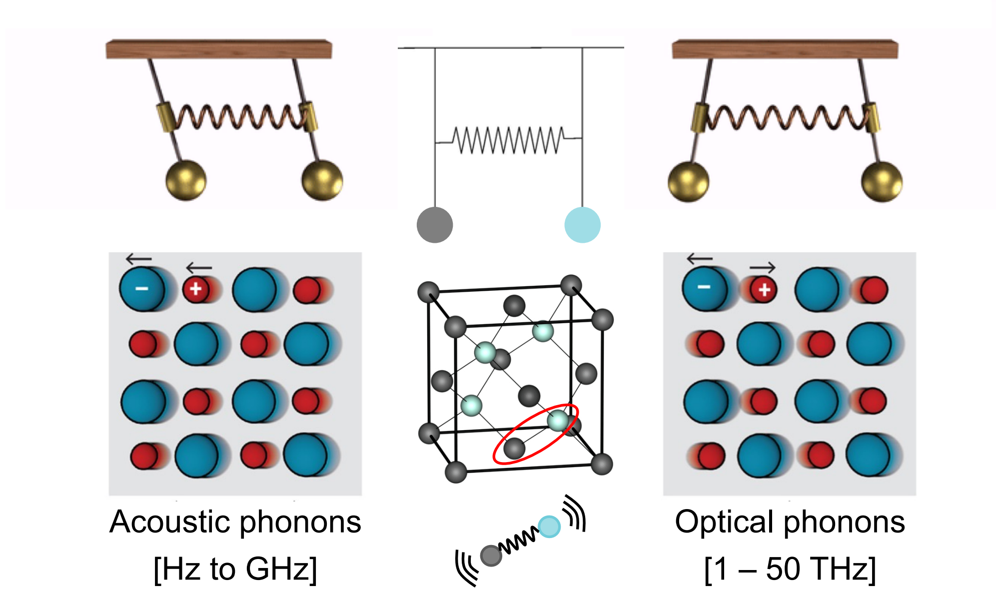


scattering probability is
< 10^{-21} per incoming photon

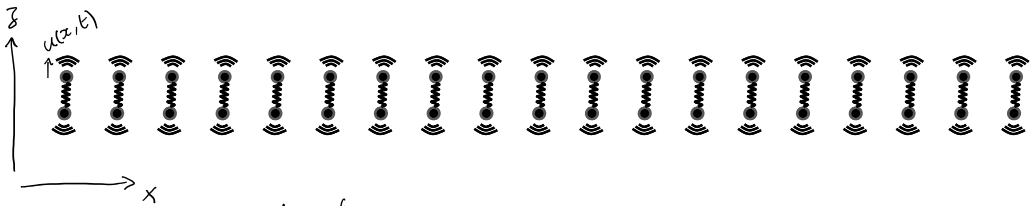
E.C. Le Ru and P. G. Etchegoin, *Principles of Surface-Enhanced Raman Spectroscopy and related plasmonic effects*, Elsevier , 2009

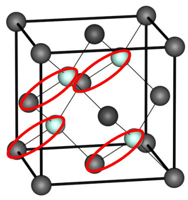
Derek A. Long, *The Raman Effect – A Unified Treatment of the Theory of Raman Scattering by Molecules,* 2002

Coupled Oscillators: Normal Modes



Collective Vibrational Modes





For each molecule : mechanical displacement (along z) : $u(x,t)$

↳ We can expand the susceptibility : $\chi = \chi_0 + \frac{d\chi}{du}\Big|_{u=0} u(x,t) = \chi_0 + \chi_R\, u(x,t)$

$$\vec{D} = \varepsilon_0 \vec{E}(x,t) + \vec{P} = \underbrace{\varepsilon_0(1+\chi_0)\vec{E}}_{\downarrow} + \underbrace{\varepsilon_0 \chi_R E_z u_z}_{\text{in 3D : } \chi_{ijk} E_j u_k}$$

$E_z(x,t) = \mathcal{E}_L(x,t) + E_z(x,t)$

→ $\mathcal{E}_L^2 u$ → shift of zero point energy

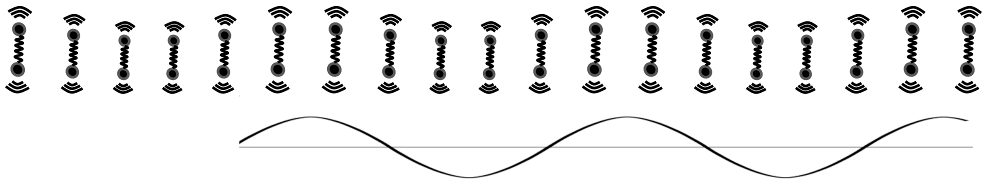
→ $E_z^2 u$ → second order

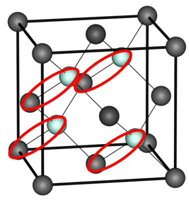
$$\mathcal{H}_{tot} = \frac{1}{2}\vec{D}.\vec{E} + \frac{1}{2}\vec{B}.\vec{B} = \mathcal{H}_{free} + \mathcal{H}_{int} \longrightarrow \underline{\mathcal{H}_{int} = \frac{1}{2}\varepsilon_0 \chi_R E_z^2(x,t)\, u(x,t)} \;\Big| \rightarrow \mathcal{H}_{int} = \varepsilon_0 \chi_R \mathcal{E}_L E_z(x,t)\, u(x,t)$$

T. von Foerster and R. J. Glauber, *Phys. Rev. A* **3** 1484 (1971)

Cohen-Tannoudji, Diu, Laloe *Quantum mechanics* vol. 1, Ch. V, complement I

Collective Vibrational Modes





Quantized mechanical waves : $u(x,t) = \sum_q \sqrt{\frac{\hbar}{2L\rho\Omega}} \Big(\underbrace{\hat{b}_q e^{i(qx-\Omega t)}}_{u^{(+)}} + \underbrace{h.c.}_{u^{(-)}} \Big)$

mass density

Similarly for the EM field : $E(x,t) = \sum_k \sqrt{\frac{\hbar\omega_k}{2L\varepsilon_0}} \Big(\underbrace{i\hat{a}_k e^{i(kx-\omega_k t)}}_{E^{(+)}} + \underbrace{h.c.}_{E^{(-)}} \Big)$

Laser : $\mathcal{E}_L = \mathcal{E}_L^{(+)} + \mathcal{E}_L^{(-)}$

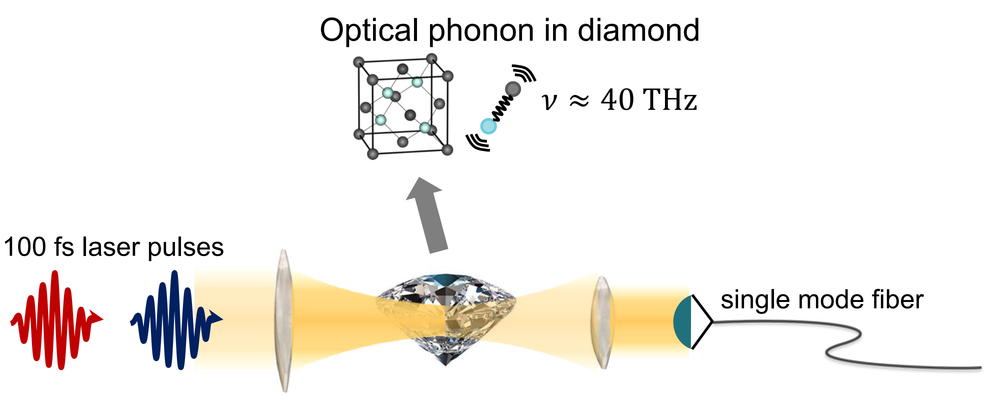
4 terms that contain $\mathcal{E}_L^{(+)} E^{(+)}$, $\mathcal{E}_L^{(-)} E^{(-)}$

↳ don't conserve energy.

T. von Foerster and R. J. Glauber, *Phys. Rev. A* **3** 1484 (1971)

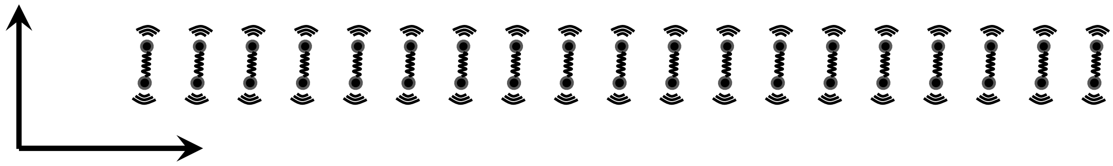
Cohen-Tannoudji, Diu, Laloe *Quantum mechanics* vol. 1, Ch. V, complement I

Light to Create and Detect a Phonon



NA 0.8 ➡ 100 billion atoms ➡ scattering probability ~10^{-10}

Light–vibration interaction Hamiltonian



Terms that remain in H_{int} are : $\mathcal{H}_{int} = \mathcal{H}_S + \mathcal{H}_A$ where $\mathcal{H}_S = \varepsilon_0 \chi_R \mathcal{E}^{(+)} E^{(-)} u^{(-)} + h.c.$

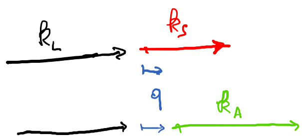
$\mathcal{H}_A = \varepsilon_0 \chi \mathcal{E}^{(+)} E^{(-)} u^{(+)} + h.c.$

	Stokes	anti Stokes
Conservation of energy :	$\omega_S + \Omega = \omega_L$	$\omega_A = \omega_L + \Omega$
of momentum :	$k_S + q_S = k_L$	$k_A = k_L + q_A$

Interaction Hamiltonian :

$$\hat{H}_S = i\hbar \left(g_S \hat{a}_S^\dagger \hat{b}^\dagger - g_S^* \hat{a}_S \hat{b} \right)$$

$$\hat{H}_A = i\hbar \left(g_A \hat{a}_A^\dagger \hat{b} - g_A^* \hat{a}_A \hat{b}^\dagger \right)$$



T. von Foerster and R. J. Glauber, *Phys. Rev. A* **3** 1484 (1971)

Two-Mode Squeezed Vacuum

Stokes interaction : $H_S = i\hbar \left(g \hat{a}^\dagger \hat{b}^\dagger - g^* \hat{a} \hat{b} \right)$

Initial state is the vacuum for Stokes and vibration : $|\Psi_{in}\rangle = |0\rangle_a \otimes |0\rangle_b$

$$|\Psi_t\rangle = \hat{U}(t)\,|vac\rangle_{a,b} \qquad \hat{U}(t) = \exp\left(\frac{tH_S}{i\hbar}\right)$$

$$= \sum_n \left(tg\,\hat{a}^\dagger \hat{b}^\dagger - tg^* \hat{a}\hat{b} \right)^n$$

Heisenberg equation of motion :

$$i\hbar \frac{\partial \hat{a}}{\partial t} = [\hat{a}, \hat{H}_S] = i\hbar g \hat{b}^\dagger \Rightarrow \frac{\partial \hat{a}}{\partial t} = g \hat{b}^\dagger \rightarrow \frac{\partial^2 \hat{a}}{\partial t} = |g|^2 \hat{a}(t) \rightarrow \hat{a}(t) = \hat{A}\cosh(|g|t) + \hat{B}\sinh(|g|t)$$

$$\frac{\partial \hat{b}}{\partial t} = g \hat{a}^\dagger$$

$$\begin{cases} \hat{a}(t) = \hat{a}_0 \cosh(\lambda t) + \hat{b}_0^\dagger e^{i\theta} \sin(\lambda t) \\ \hat{b}(t) = \hat{b}_0 \cosh(\lambda t) + \hat{a}_0^\dagger e^{i\theta} \sin(\lambda t) \end{cases} \qquad g = \lambda e^{i\theta}$$

$$\hat{a}(t) = \hat{U}^\dagger(t)\,\hat{a}_0\,\hat{U}(t)$$

$$\hat{a}_0 = \hat{U}(t)\,\hat{a}_t\,U^\dagger(t)$$

C. C. Gerry and P. L. Knight, Intro to Quantum Optics (2005) Ch. 7

Ulf Leonhardt - Measuring of Quantum State of Light (1997), Ch. 2.3

Two-Mode Squeezed Vacuum

* H_S creates pairs (it commutes with $\hat{n}_a - \hat{n}_b$) $\rightarrow |\Psi_t\rangle = \sum_n \alpha_n |n,n\rangle$

* $\hat{a}|0,0\rangle = 0 \Rightarrow \hat{U}(t)\,\hat{a}\,|0,0\rangle = 0 \Rightarrow \underbrace{\hat{U}(t)\,\hat{a}\,U^{\dagger}}\,\underbrace{U\,|0,0\rangle}_{|\Psi_t\rangle} = 0$

$|\Psi_t\rangle$ is an eigenvector of $\cosh(\lambda t)\,\hat{a}_0 - e^{i\theta}\sinh(\lambda t)\,b_0^{\dagger}$

↳ $\sum_n \alpha_n \left(\sqrt{n}\cosh(\lambda t)\,|n-1,n\rangle - \sqrt{n+1}\,e^{i\theta}\sinh(\lambda t)\,|n,n+1\rangle\right) = 0$

$\Rightarrow \alpha_{n+1}\cosh(\lambda t) = \alpha_n e^{i\theta}\sinh(\lambda t) \Rightarrow \alpha_n = \alpha_0 \left(e^{i\theta}\tanh(\lambda t)\right)^n$

$\sum_n |\alpha_n|^2 = 1 \Rightarrow \alpha_0 = \frac{1}{\cosh(\lambda t)} \Rightarrow |\Psi_t\rangle = \frac{1}{\cosh(\lambda t)} \sum_n e^{in\theta}\tanh^n(\lambda t)\,|n,n\rangle$

$= \sqrt{1-|\tilde{p}|^2}\,\sum_n \tilde{p}^n\,|n,n\rangle$

Marginal state (information is lost about the other mode):

$\hat{\rho}_a = tr_a(\hat{\rho}_{squeezed}) = (1-p)\sum_n p^n\,|n\rangle\langle n|_a$ if I write $p = \frac{\bar{n}}{1+\bar{n}}$

↳ Thermal state with $\bar{n}$ mean occupancy.

Outline

State of the art: Mechanical Oscillators in the Quantum Regime

Milestone 1: Preparation and Readout of a Single Phonon

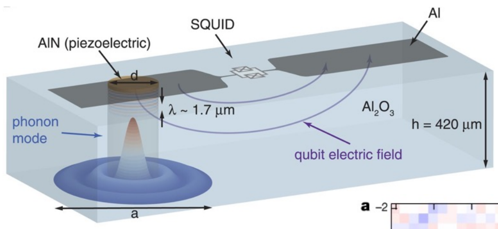
Milestone 2: Bell Correlations between Light and Vibrations

Perspectives: Synthetic Quantum Systems

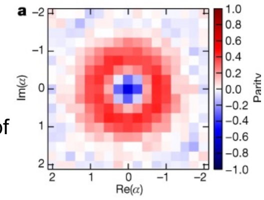
Mechanical Oscillators in the Quantum Regime

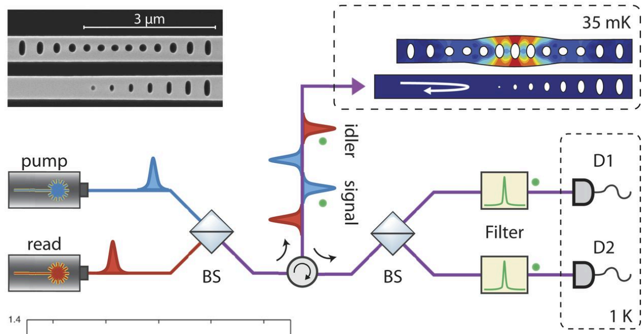
Mechanical Frequency: 5 – 6 GHz

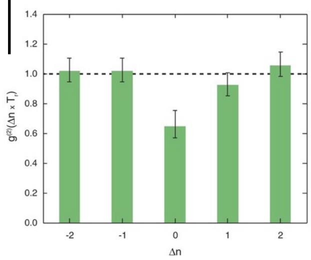
Bath Temperature: 20 – 40 mK



Y. Chu, … P. Rakich, R. Schoelkopf
Science (2017), ***Nature*** (2018)



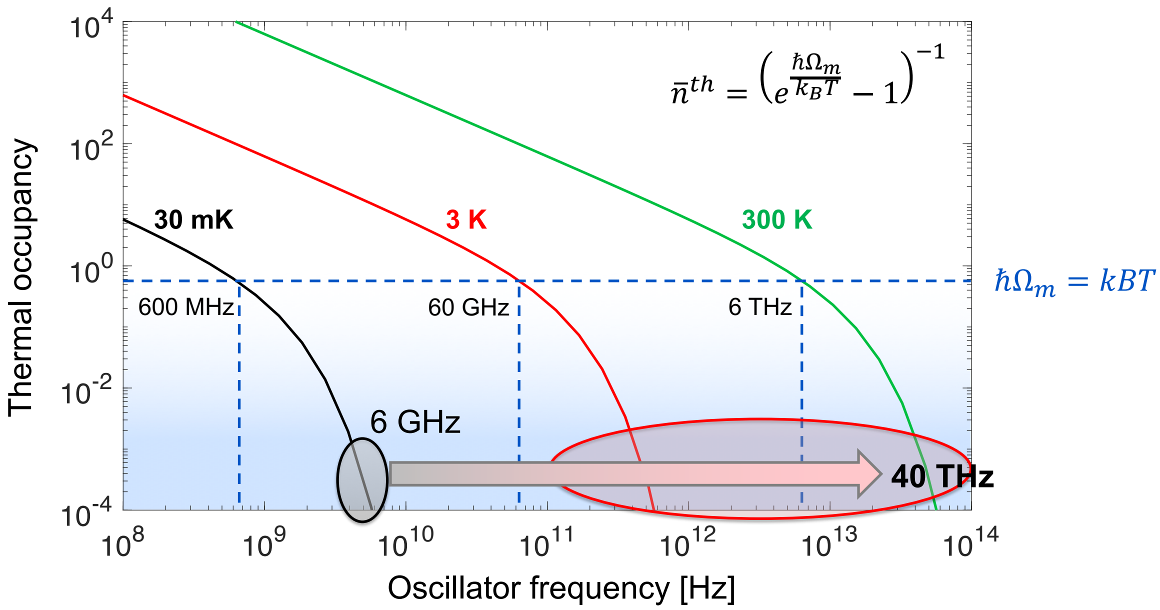




R. Riedinger, ... M. Aspelmeyer & S. Gröblacher
Nature (2016), ***Science*** (2017), ***Nature*** (2018)…

1st milestone: Phonon Fock state generation

Mechanical Oscillators in the Quantum Regime



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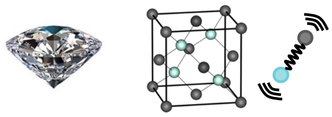
Light to Create and Detect a Phonon

Optical phonon in diamond

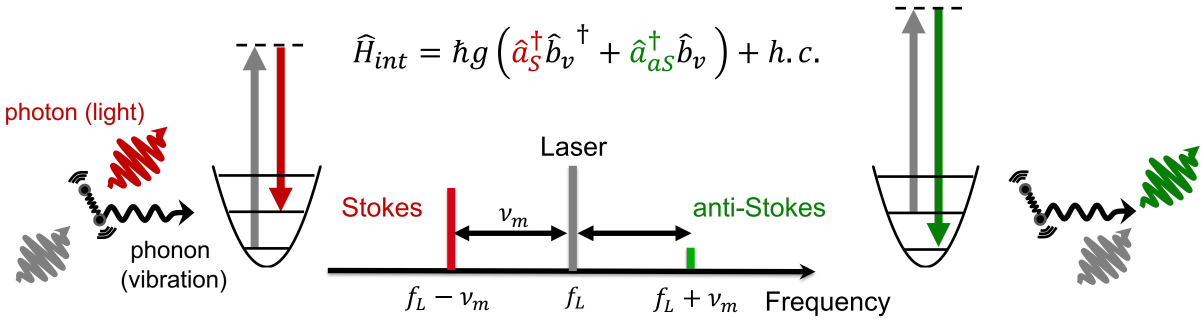
At room temperature



$\nu \approx 40$ THz

$n_{therm} \approx 10^{-3}$

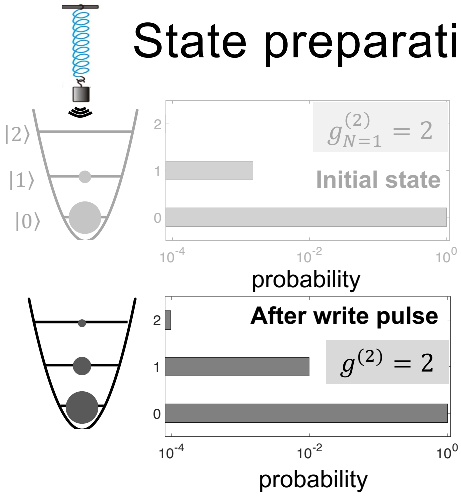
$$\hat{H}_{int} = \hbar g \left(\hat{a}_S^{\dagger} \hat{b}_v^{\dagger} + \hat{a}_{aS}^{\dagger} \hat{b}_v \right) + h.c.$$



K. C. Lee …, Ian Walmsley *et al. Science* (2011)
K. C. Lee, …, Ian Walmsley *Nat. Photon.* (2012)

Benjamin Sussman (*PRL* 2013, *PRL* 2015, *Nat. Comm.* 2016…)
M Kasperczyk, *Opt. Lett.* (2015); Ado Jorio (*PRL* 2017…)

State preparation by projective measurement

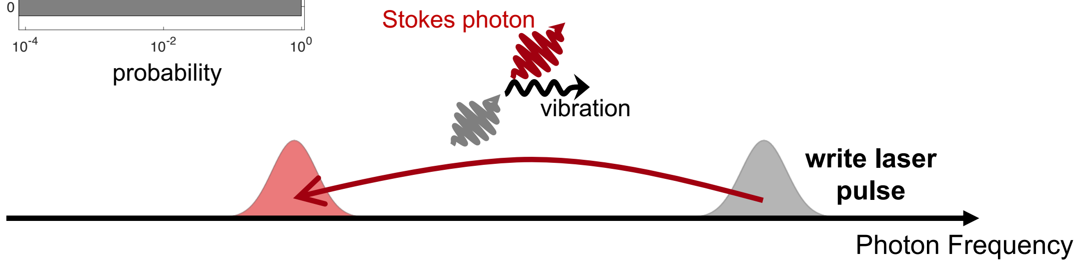


N modes: $g_N^{(2)} = 1 + 1/N$

$$\hat{H}_{int} = \hbar g \left(\hat{a}_S^{\dagger} \hat{b}_v^{\dagger} + \hat{a}_{as}^{\dagger} \hat{b}_v \right) + h.c.$$

$$|\Psi_{S,m}\rangle \propto |0_S, 0_v\rangle + \sqrt{p}|1_S, 1_v\rangle + p|2_S, 2_v\rangle + \ldots$$

Two-mode squeezed state

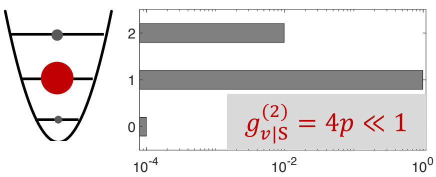


State preparation by projective measurement

Vibrational state after heralding

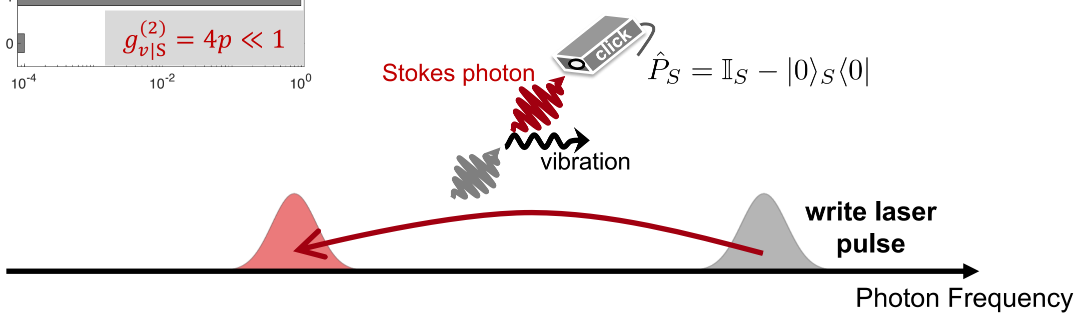
$$|\rho_v\rangle \approx |1_v\rangle\langle 1_v| + p|2_v\rangle\langle 2_v|$$

?



$$|\Psi_{S,m}\rangle \propto \cancel{|0_S, 0_v\rangle} + \sqrt{p}|1_S, 1_v\rangle + p|2_S, 2_v\rangle + \ldots$$

$$\hat{P}_S = \mathbb{I}_S - |0\rangle_S\langle 0|$$



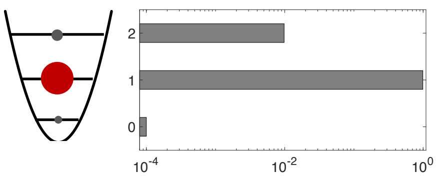
Vibrational State read-out

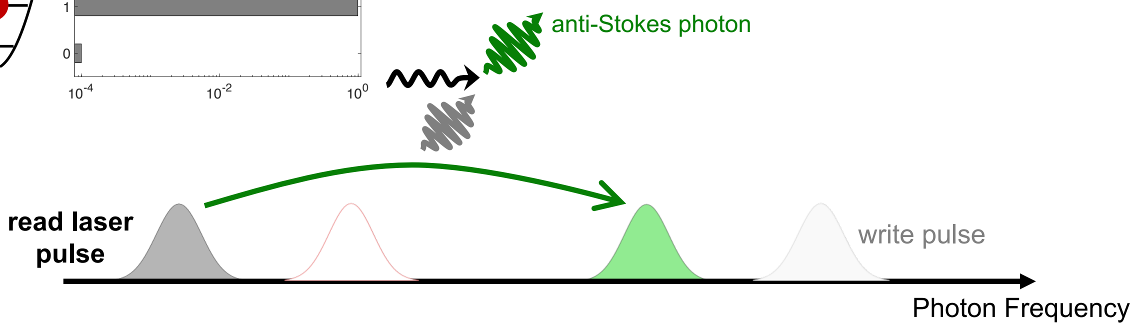
Vibrational state after heralding

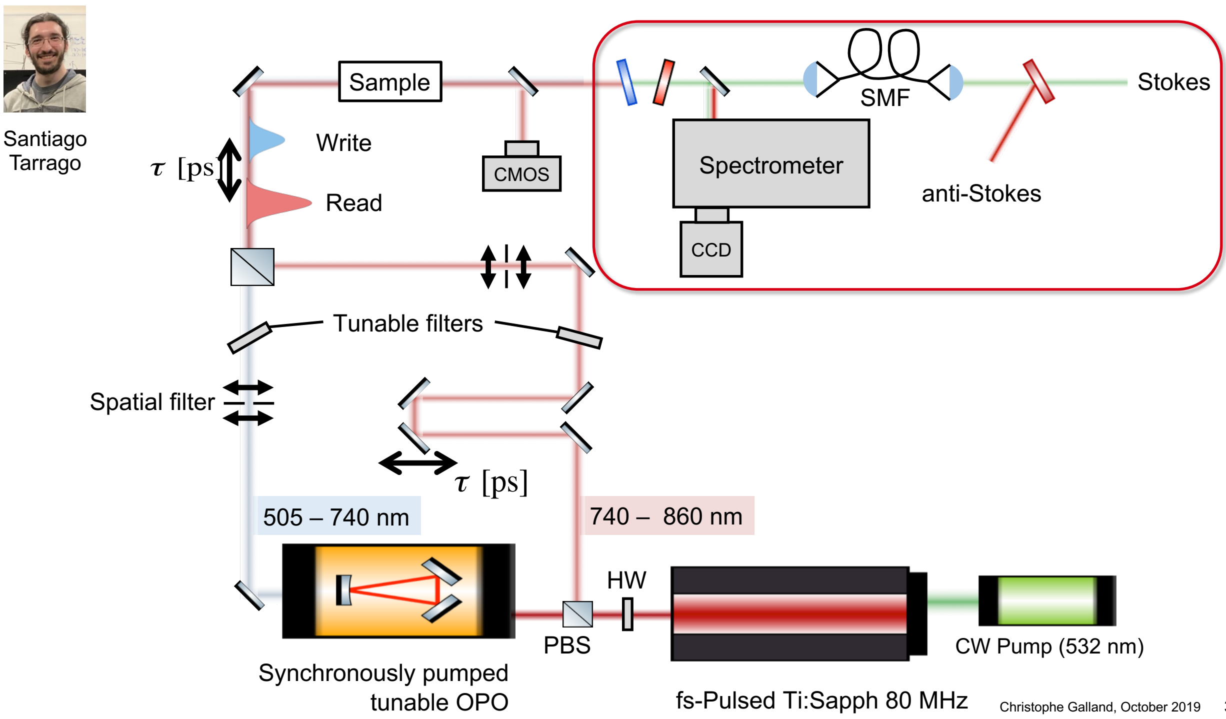
$|\rho_v\rangle \approx |1_v\rangle\langle 1_v| + p|2_v\rangle\langle 2_v|$ **?**

$$\hat{H}_{int} = \hbar g\left(\hat{a}_S^\dagger \hat{b}_v^\dagger + \hat{a}_{aS}^\dagger \hat{b}_v\right) + h.c.$$

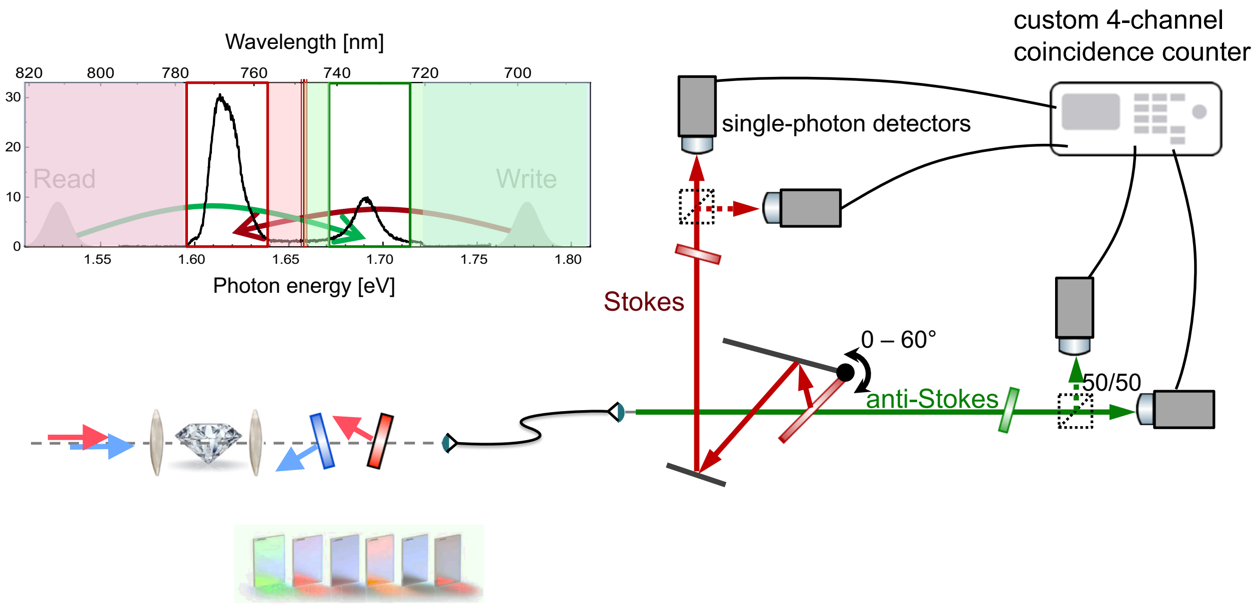
$$|0_{aS}, 1_v\rangle \rightarrow \sin(\beta)|1_{aS}, 0_v\rangle + \cos(\beta)|0_{aS}, 1_v\rangle$$





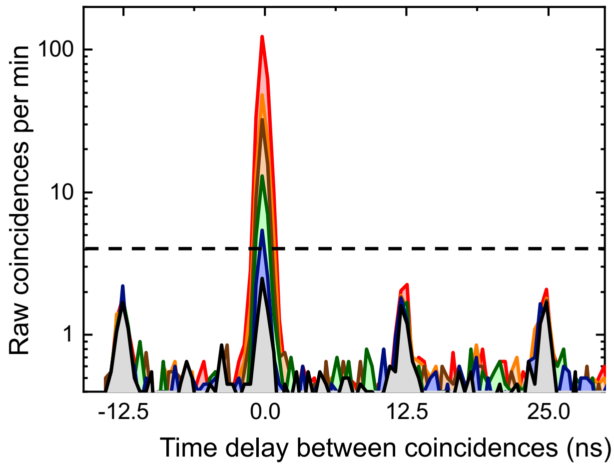


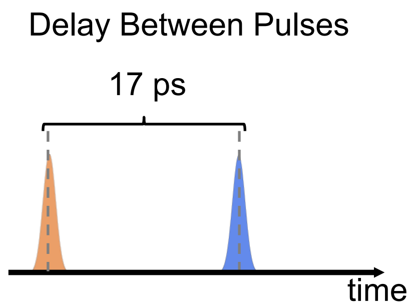
Sideband Single-photon Detection



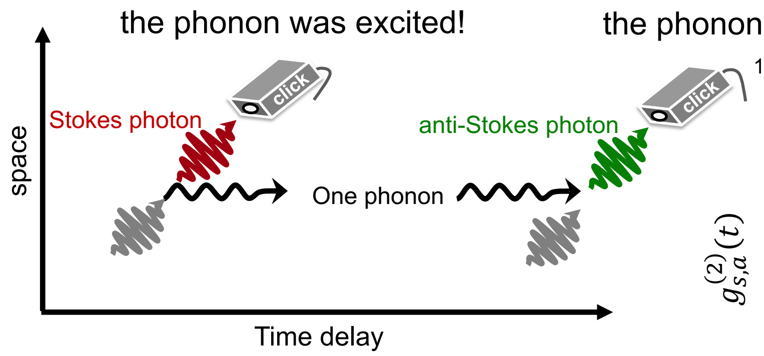
Tunable interference filters

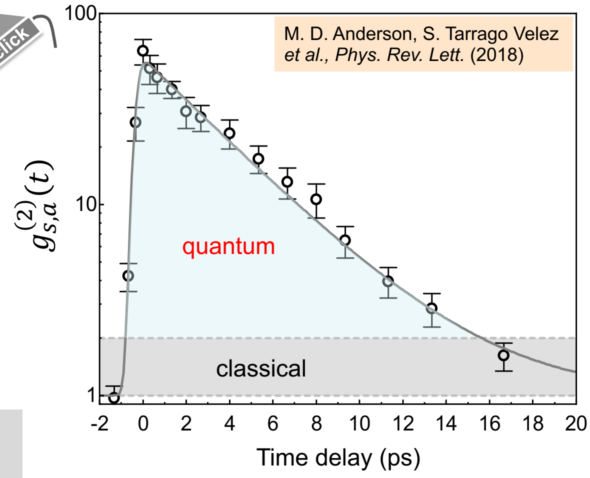
Phonon-mediated two-color quantum correlations





Birth and death of a single phonon

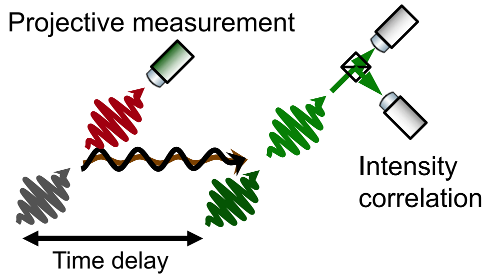


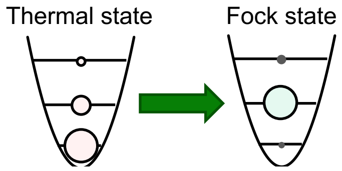


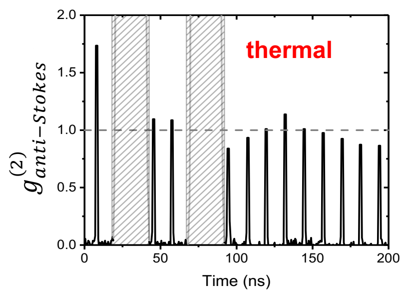
Classical fields satisfy a form of triangular inequality:

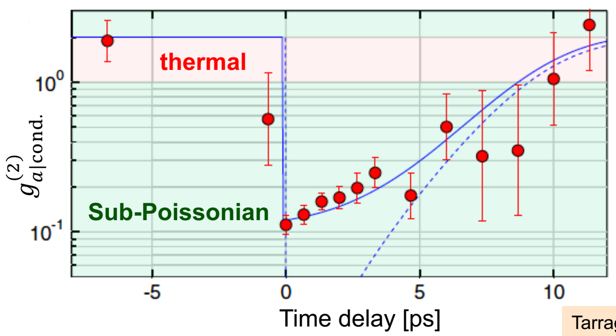
$$g^{(2)}_{s,a}(t) \leq \left(g^{(2)}_{s,s}(t)\; g^{(2)}_{a,a}(t)\right)^{1/2}$$

Phonon Fock State Preparation









Tarrago Velez et al. ***Phys. Rev. X*** (2019)

Optomechanical cavity at 35 mK: $g^{(2)} = 0.6$ [S. Hong *et al. Science* 358, 203–206 (2017)]

Outline

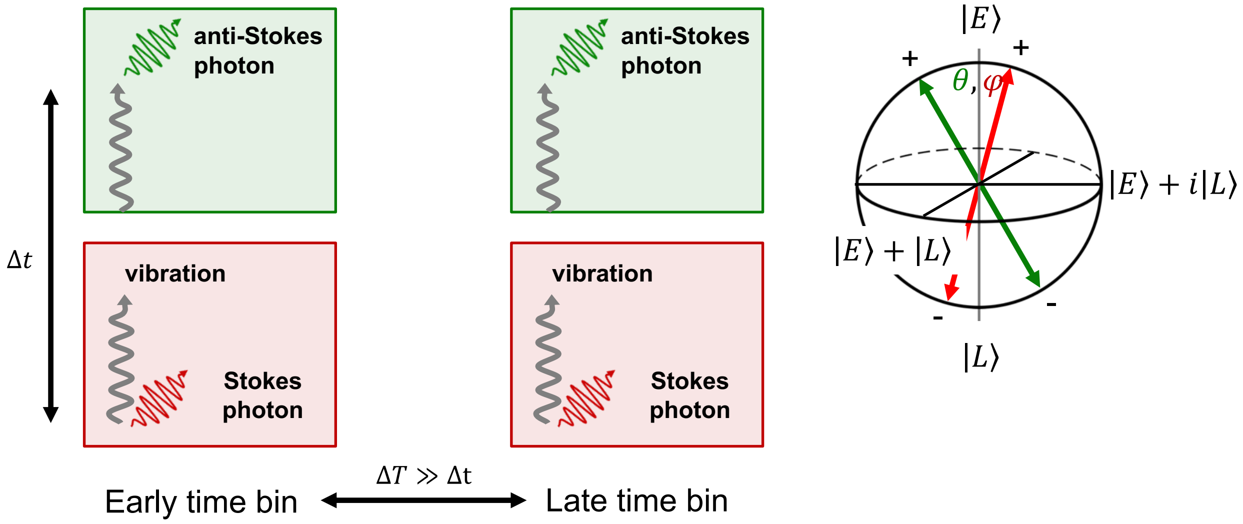
State of the art: Mechanical Oscillators in the Quantum Regime

Milestone 1: Preparation and Readout of a Single Phonon

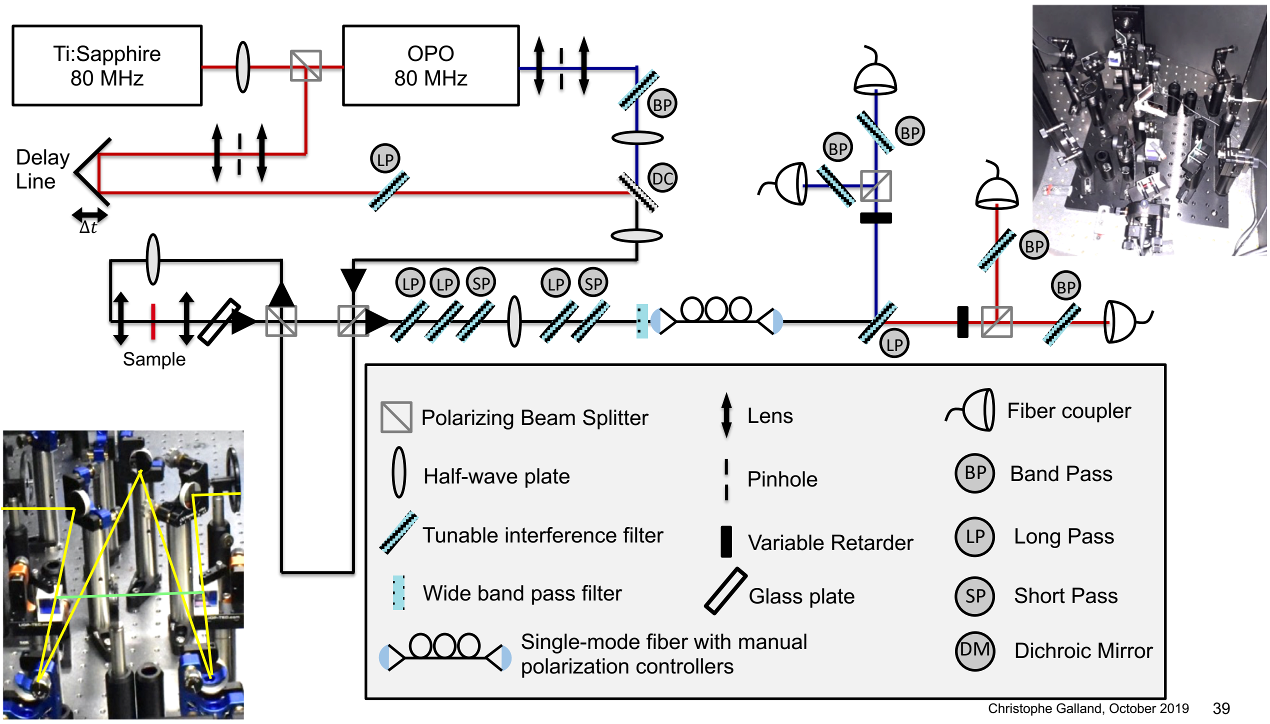
Milestone 2: Bell Correlations between Light and Vibrations

Perspectives: Synthetic Quantum Systems

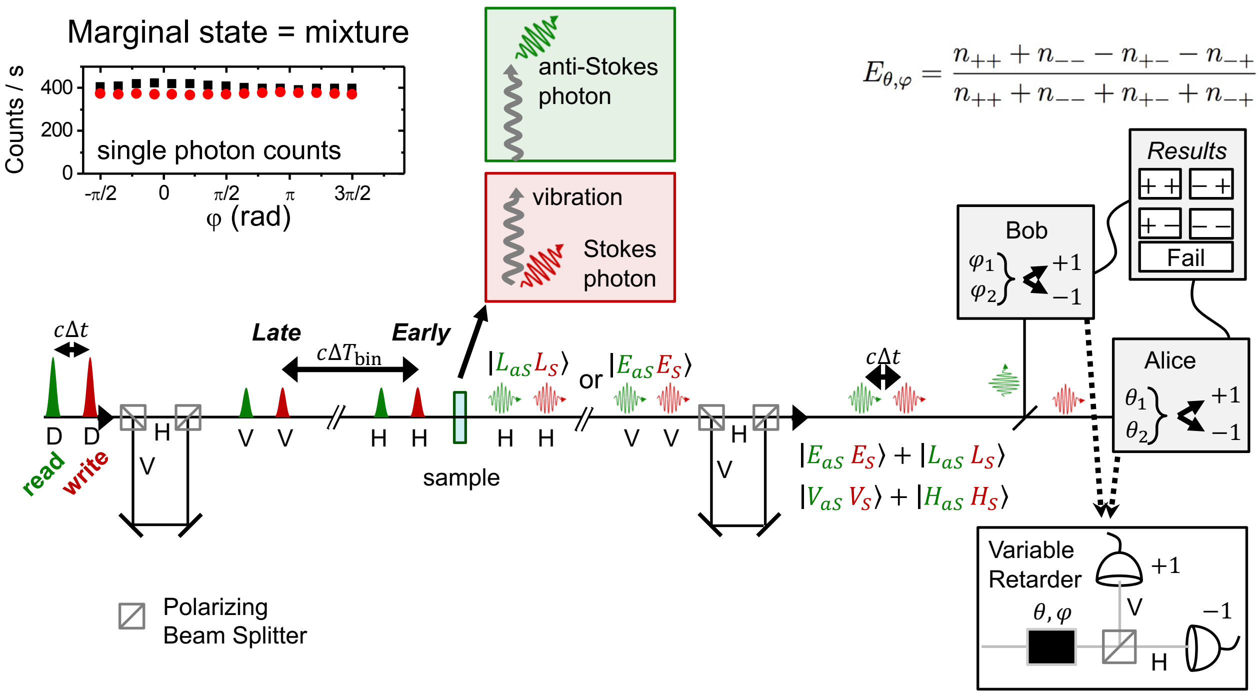
Time-bin entanglement



$$|E_{aS}\, E_S\rangle + |L_{aS}\, L_S\rangle$$



Ti:Sapphire
80 MHz
OPO
80 MHz
Delay
Line
Δt
BP
LP
DC
SP
Sample
Polarizing Beam Splitter
Half-wave plate
Tunable interference filter
Wide band pass filter
Single-mode fiber with manual polarization controllers
Lens
Pinhole
Variable Retarder
Glass plate
Fiber coupler
Band Pass
Long Pass
Short Pass
DM
Dichroic Mirror

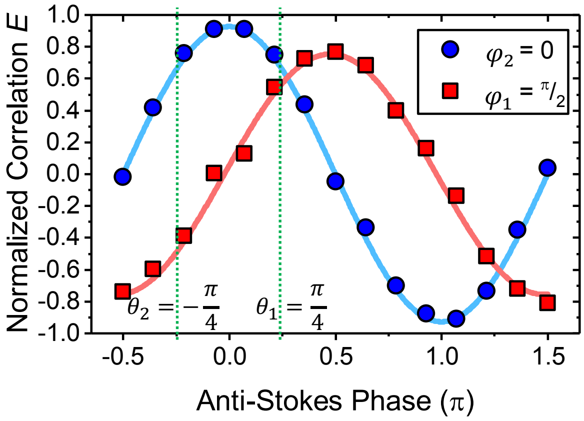


Marginal state = mixture
Counts / s
400
200
0
single photon counts
-π/2
0
π/2
π
3π/2
φ (rad)
anti-Stokes
photon
vibration
Stokes
photon
$E_{\theta,\varphi} = \frac{n_{++} + n_{--} - n_{+-} - n_{-+}}{n_{++} + n_{--} + n_{+-} + n_{-+}}$
Results
+ +
− +
+ −
− −
Fail
Bob
φ_1
φ_2
+1
−1
Alice
θ_1
θ_2
$c\Delta t$
Late
Early
$c\Delta T_{\text{bin}}$
$|L_{as} L_S\rangle$ or $|E_{as} E_S\rangle$
D
D
read
write
H
V
sample
$|E_{as}\ E_S\rangle + |L_{as}\ L_S\rangle$
$|V_{as}\ V_S\rangle + |H_{as}\ H_S\rangle$
Variable
Retarder
θ, φ
Polarizing
Beam Splitter

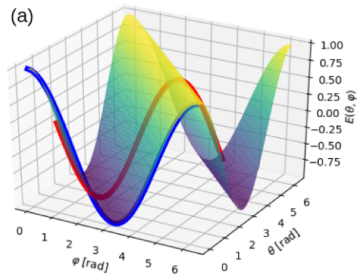
Two-photon interference and Bell correlations

write – read delay = 0.6 ps

$$S = E_{\theta_1,\varphi_1} + E_{\theta_2,\varphi_2} + E_{\theta_1,\varphi_2} - E_{\theta_2,\varphi_1} \qquad S = 2.36 \pm 0.02 > 2$$

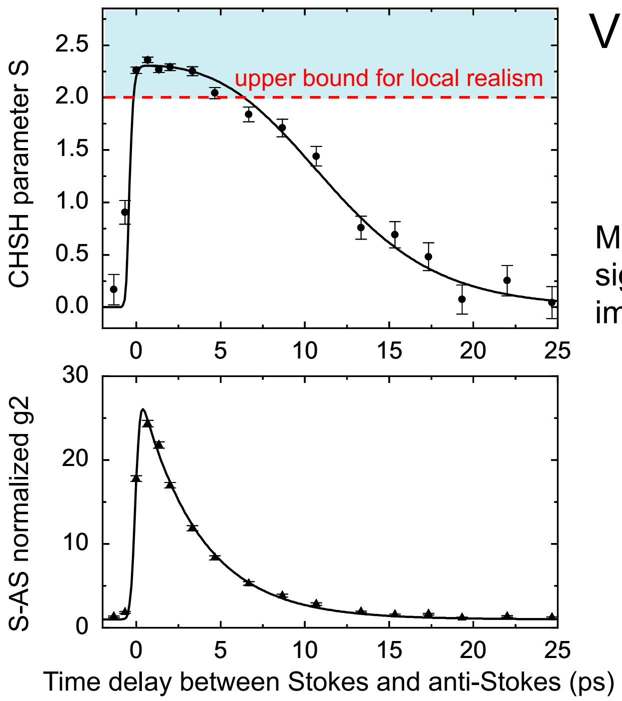


V = 93% and 75%

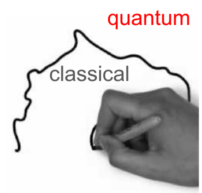


mK experiments:

R Riedinger, … S Gröblacher, *Nature* 556, 473 (2018)
I Marinkovic, … S Gröblacher, *Phys. Rev. Lett.* 121, 220404 (2018).

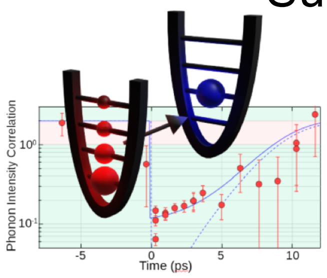


Vibrational qubit decoherence



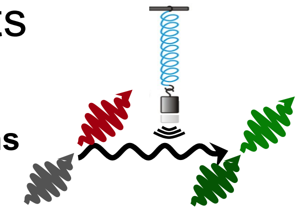
Model inputs:
signal-to-noise (from $g^{(2)}_{S,aS}$)
imperfect time overlap (birefringence)

Summary of experimental results



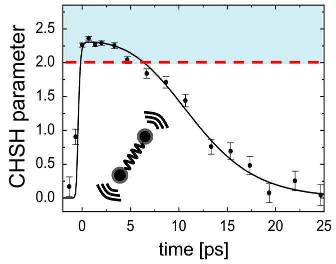
Tarrago et al. ***Phys. Rev. X*** (2019)

Ultrafast technique to probe
Optomechanical Quantum Correlations



Anderson et al. ***Phys. Rev. Lett.*** (2018)

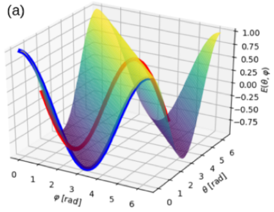
Birth and Death of a
Heralded Single Phonon
at ambient conditions



Tarrago et al. ***to be submitted***

Bell correlations between
light and vibration
at room temperature

Decoherence of a vibrational qubit



Two-photon interference

Christophe Galland, October 2019 43

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Hossein Babashah
Sakthi Priya
Santiago Tarrago

Postdocs:
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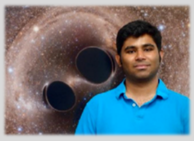
The team @LQNO

FNSNF erc European Research Council FET Horizon2020 LakeDiamond

Collaborations



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